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WHAT CONSTITUTES NATIONAL SECURITY IN THE SEMICONDUCTOR INDUSTRY? A LOOK AT THE COMPETING VIEWS SURROUNDING DOD'S SUPPORT OF SEMICONDUCTORS

by

William A. Johnson

Thesis Advisor: William Gates

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This thesis examines the current views surrounding federal support of the semiconductor industry, specifically from the Department of Defense. "National security" is often cited as a reason for federal intervention in the industry. How well founded are the arguments for this support? The current situation in the domestic semiconductor industry is examined, and the industy's explanations for recent changes in market position are identified. Prevailing economic theory is reviewed for possible alternative explanations. Industry views are then examined in light of this economic theory, and appropriate federal actions are recommended. Since these recommendations focus on the macroeconomic forces influencing the balance of trade, they will benefit the semiconductor industry and the economy as a whole.

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What Constitutes National Security
in the Semiconductor Industry?
A Look at the Competing Views Surrounding
DoD's Support of Semiconductors

by

William A. Johnson
Captain, United States Marine Corps
B.S., Auburn University

Submitted in partial fulfillment
of the requirements for the degree of

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December 1990

Author: William A. Johnson
William A. Johnson

Approved by: William Gates
William Gates, Thesis Advisor

Katsuaki Terasawa
Katsuaki Terasawa, Second Reader

David R. Whipple
David R. Whipple, Chairman,
Department of Administrative Sciences

ABSTRACT

This thesis examines the current views surrounding federal support of the semiconductor industry, specifically from the Department of Defense. "National security" is often cited as a reason for federal intervention in the industry. How well founded are the arguments for this support? The current situation in the domestic semiconductor industry is examined, and the industry's explanations for recent changes in market position are identified. Prevailing economic theory is reviewed for possible alternative explanations. Industry views are then examined in light of this economic theory, and appropriate federal actions are recommended. Since these recommendations focus on the macroeconomic forces influencing the balance of trade, they will benefit the semiconductor industry and the economy as a whole.

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I. INTRODUCTION and BACKGROUND

The United States armed forces have relied heavily on the "force multiplying" effect of technology. The importance of technology in the conduct of war is demonstrated in the words of the former Chief of the Soviet General Staff, Field Marshal Nikolai Ogarkov:

> [R]apid changes in the development of conventional means of destruction in the developed countries of automated,...long range, high-accuracy,...combat systems,...and qualitatively new electronic control systems makes many types of weapons global and makes it possible to sharply increase...the destructive potential of conventional weapons, bringing them closer...to weapons of mass destruction in terms of [their] effectiveness. (Gliksman, 1990, p.38)

Maintaining a lead in this technological development has been the aim of the United States armed forces for some time, and at the root of this growing technology lies the semiconductor. The importance of the electronics and semiconductor industries to the national defense has been voiced many times. In the words of Craig Fields, former director of DARPA, "nothing is more essential for superiority in almost every type of conventional weapon." (Smith, 1989, p.254) Voicing similar opinions, Secretary of Defense Richard Cheney noted that "these technologies form the core of [our] future capabilities in anti-submarine, electronic and strategic warfare, low-intensity conflict, special operations and other military missions." (Struck, 1990, p.10)

During a time when America is reducing her forces, electronics will play an ever increasing role in the defense of our country. While reliance on semiconductors continues to rise, however, there is a growing perception that the United States is losing the technological edge in semiconductors to other countries, specifically the Japanese. With DARPA spending millions of dollars a year to fund research and support this critical industry, a closer look at the forces acting on it may help identify what actions will improve our competitive situation in the future.

A. THE AMERICAN INDUSTRY

America emerged from the second world war as the preeminent superpower in the world. Its strength lies in the power of her military and the vitality of the economy. Until the early 1980s, America's economic position went virtually unchallenged. Since that time, however, the Japanese and the Europeans have made strong economic advances, with the automobile and electronics industries being the most obvious examples of where the United States has lost market share and some of its world leading position.

At the heart of the growth in the electronics industry lies the semiconductor. Americans have invented and manufactured electronic devices for some time, but the pace and expansion of the industry really exploded after the invention of the transistor at Bell Laboratories in 1949. The transistor, the first semiconductor, allowed the miniaturization of electronics by replacing the bulkier and more fragile vacuum tube. The first integrated circuit, containing multiple transistors on one silicon chip, was invented by Jack Kilby and Robert Noyce in 1959. These two major advances accelerated the growth of electronics and created what we know today as the semiconductor industry. (SIA, 1989, p.3)

1. The "Food Chain" Analogy

Since that time, the semiconductor industry has grown to be a multi-billion dollar industry, feeding an even larger electronics industry. Dr. James Gover, member of the Semiconductor Products Division of the Sandia National Labs, uses the "food chain" analogy shown in Figure 1.1 to describe the interdependence of the industry. Semiconductor materials and manufacturing equipment producers make up a very small portion of the industry, feeding the semiconductor manufacturers. The semiconductor manufacturers, in turn, feed a much larger electronics industry composed of products from cameras to computers (Gover, 1990). For example, the American semiconductor industry had revenues of $13.4 billion in 1988, making possible the production of $278.9 billion worth of electronics in the same year (SIA, 1989, p.3). Electronics play a vital role in our economy. Everything from automobiles to toasters make use of some type of semiconductor.

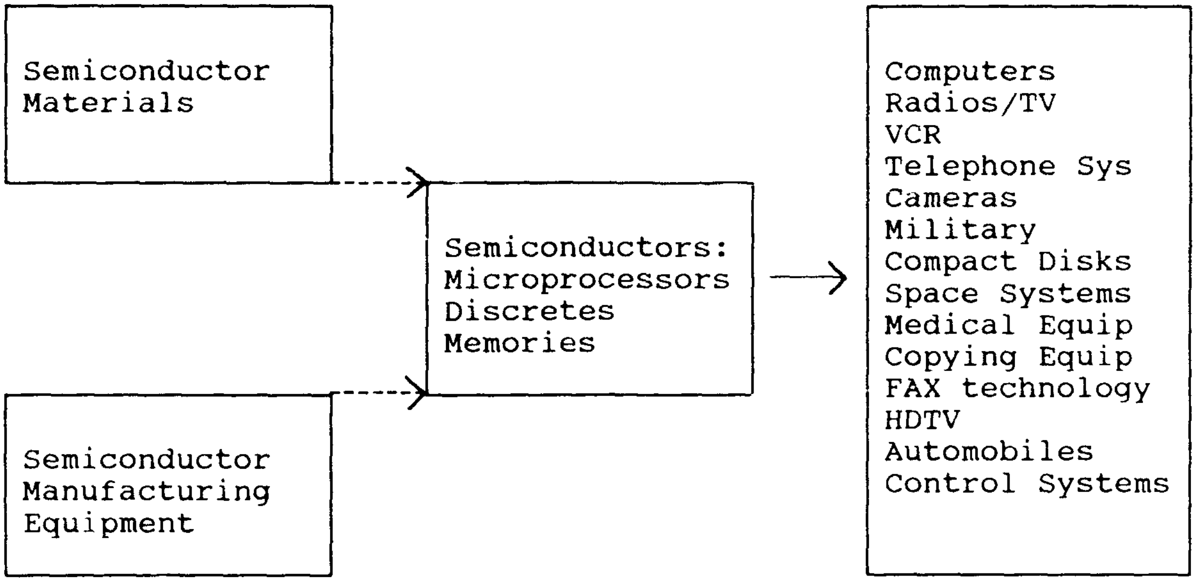

Figure 1.1 Diagram of the "Food Chain" Concept: The Multi-Tiered Electronics Industry.

2. Merchant and Captive Producers

American companies manufacturing semiconductors can be grouped into two broad categories. "Merchant" companies produce semiconductors for sale to electronics manufacturers. Examples of merchant producers include Advance Micro Devices, Intel, Motorola, National Semiconductor, and Texas Instruments. "Captive" companies manufacture semiconductors solely for use in their parent company's products. IBM , AT&T, and Digital Equipment Corporation are well known examples of American captive producers (Nordwall, 1987, p.94). This production focus impacts the performance of the firm significantly. Merchant producers compete against themselves and foreign firms; they are subject to price fluctuations and the competitive marketplace. Captive producers are not subject to the fluctuating chip prices of the market situation; their revenues are based on the sale of their final electronic products. (SIA, 1989, p.3)

The category in which the semiconductor manufacturer falls may also impact on his level of research and development. American semiconductor manufacturers have historically spent between 8 and 14 percent of their total sales on research and development (SIA, 1989, p.4). However, American spending slipped to between 6 to 7 percent of sales in the late 1970s and early 1980s (The Economist, 1988, p.65). Captive manufacturers are often in a better position to invest in research and development because their revenues are not directly tied to the semiconductor market. Japanese semiconductor makers are good examples of "captive" producers that also sell in the open marketplace. They are part of integrated conglomerates that guarantee them an in-house customer (Nordwall, 1987, p.94). This situation may help explain why the Japanese have maintained a level of spending in research and development equal to 12 to 15 percent of sales over the past decade (The Economist, 1988, p.4).

B. THE JAPANESE INDUSTRY

Recent Japanese culture has evolved around self-sacrifice and teamwork for the good of the whole. It is not surprising that this current culture has spilled over into Japanese investment and business practices. American emphasis and culture revolve around ingenuity and entrepreneurship in a free and open market. Even American antitrust laws favor open competition at the expense of cooperation among firms. This different philosophy on the conduct of business has proven to be significant in the world semiconductor market.

1. U.S. Perception of the Japanese Focus

In Japan, there is a much greater emphasis on cooperation between industry and government. In the view of the American semiconductor industry, the Ministry of Trade and Industry (MITI) targets specific American industries for Japanese leadership. The existence of these specific industry goals and strategies have allowed Japanese corporations to be extremely effective in the global marketplace. The Semiconductor Industry Association (SIA), an American organization of semiconductor manufacturers, has outlined what they perceive to be the significant differences between the Japanese and American approach to the semiconductor marketplace. (SIA, 1989, pp.6-8)

a. National Industrial and Trade Policy

As already discussed, the SIA feels that MITI targets specific global markets for Japanese leadership while protecting its domestic market from severe foreign competition. Even after trade restrictions were lifted in

1975, America's share of the Japanese market has grown little. While America's share of other global markets ranges from 50 percent to 80 percent, the American share of the Japanese market averages just 10 percent (SIA, 1989, p.7). One inference that can be drawn from this unchanging position is a protected Japanese marketplace. However, many other factors, including technological change, can explain the lack of American growth in this area.

b. Company Structure

Japanese semiconductor manufacturers are vertically integrated divisions of large conglomerates. These divisions are "captive" producers that also sell chips on the open market in direct competition with smaller American "merchant" firms. The SIA feels that American firms may be at a disadvantage competing with these larger Japanese corporations. The relative size of Japanese firms as compared to American firms is demonstrated in the revenues chart shown in Figure 1.2 on the following page.

c. Capital Availability

Japanese industry is organized into large groups which are comprised of manufacturers, banks and insurance companies. American antitrust laws may forbid the establishment of such close relationships in the United States. Through these organizations, coupled with the much higher national savings rate, the Japanese semiconductor

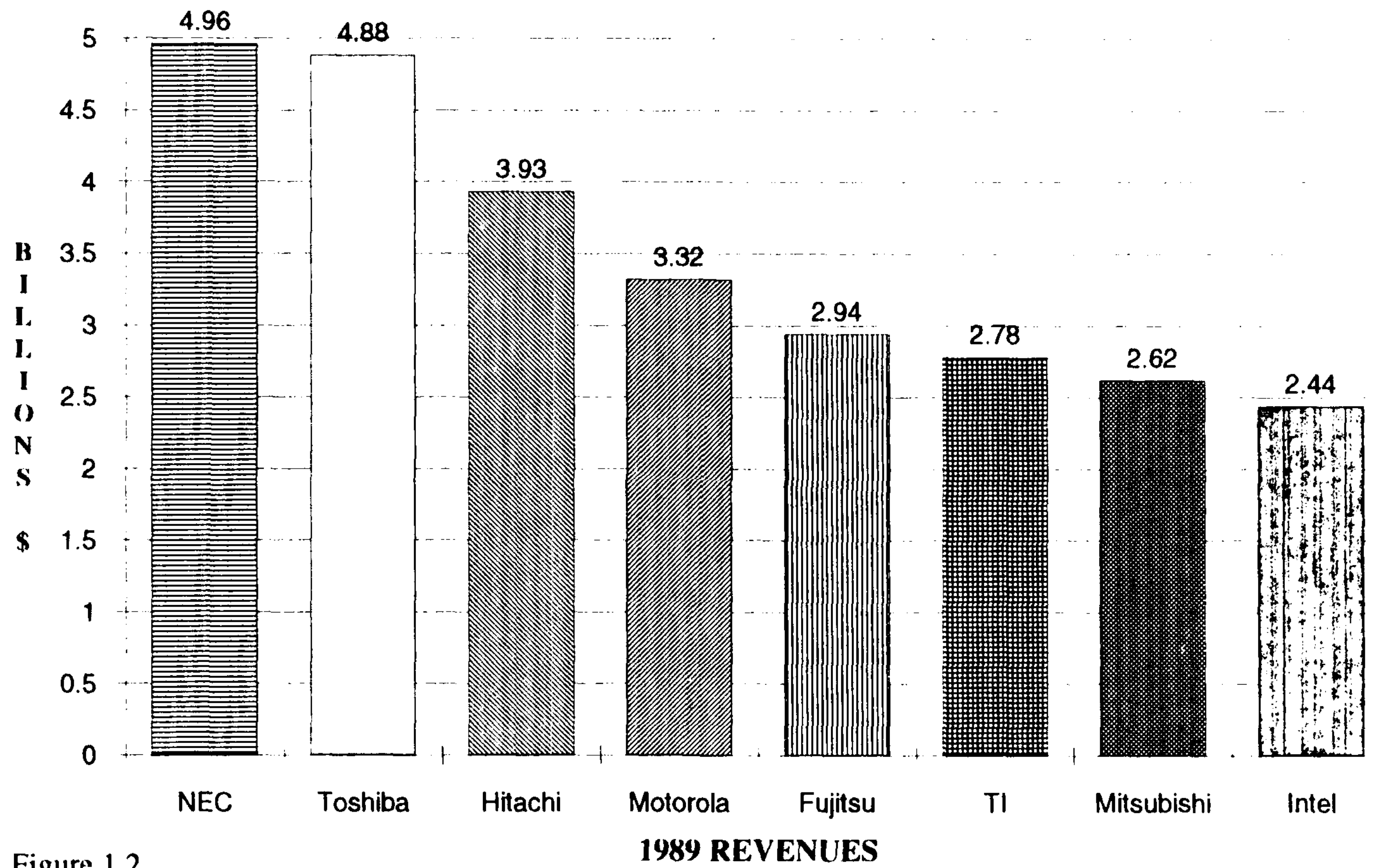
BILLIONS $
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
4.96
4.88
3.93
3.32
2.94
2.78
2.62
2.44
NEC
Toshiba
Hitachi
Motorola
Fujitsu
TI
Mitsubishi
Intel
1989 REVENUES

Figure 1.2

producers have access to large investment capital at reasonable rates. American producers must raise capital in the traditional way, through sales of stock or increased debt.

d. Management Style

Japanese companies plan in much longer cycles than their American counterparts. Less emphasis is placed on short term profitability, and the long term planning goal is stressed. The Japanese culture of working toward goals that will improve the good of the whole are evident in their choice of management style. Japanese corporations also tend to focus better on their "core competencies", the strengths that are at the root of the organization, than their American counterparts (Prahalad and Hamel, 1990, p.80). The ability to focus on the longer term has helped them to compete effectively in the semiconductor marketplace.

2. Japanese Point of View

While the SIA has used the term "targeting" to describe the trade policies of MITI, the Electronics Industry Association of Japan (EIAJ) puts forth a different view of Japanese actions. EIAJ is quick to point out that MITI has attempted to improve the environment in the electronics industry in an effort to create vigorous private sector activity. MITI has not encouraged or supported the formation of cartels or other industry restructuring. EIAJ also points out that there are benefits from joint research activities, but those actions do not inhibit free competition. Co-operative research associations in Japan are limited to research activities and technical assistance, and research associations come under the supervision of the Fair Trade Commission. The EIAJ admits that direct financial assistance is provided to some companies. However, the assistance provided is much less of a benefit to Japanese firms than the United States investment tax credit was to American companies. (OECD, 1985, p.70)

C. TECHNOLOGY

Before focusing on the current market conditions in the semiconductor industry, a brief look at the technology involved in the manufacture of semiconductors, along with some of the terminology used to describe the variety of "chips" produced, will be helpful in our analysis.

1. Manufacturing Technology

The manufacturing of semiconductors is a tedious and delicate process, involving many steps, in which hundreds of copies of an integrated circuit are formed on a silicon wafer. The manufacture consists of four basic steps: wafer production, wafer fabrication, electrical testing, and assembly. Wafer fabrication is the most complex and difficult part of the processes.

Wafer production first takes purified silicon, created from sand, and heats it until melted. A "seed" of solid silicon is then placed in the liquid and a large crystal is allowed to form. This crystal "ingot" is then ground and cut into thin "wafers". These wafers are ground and chemically polished until smooth. The wafer is the raw material in the next step, the fabrication process.

The fabrication process takes place in a clean room where a series of steps are conducted on the wafer to form the integrated circuit. The oxidation step forms a uniform silicon dioxide film on the surface of the wafer. The masking step, referred to as photolithography, applies a light sensitive film to the wafer and then "exposes" the film to intense light. A mask pattern is then left on the surface of the wafer. The etching step removes the photoresist, much like film is developed, and the wafer is baked hard to retain the pattern. Chemical baths then etch away the pattern not covered by the hardened photoresist. The Doping step implants electrons, which alter the electrical character of the silicon, into the pattern that was etched away. These oxidation, masking, etching, and doping steps are repeated many times until complex circuits are formed in the wafer. The dielectric deposition and metallization step connects the individual devices with metal depositions and patterned insulators. The passivation step then forms a final dielectric layer to protect the circuit from contamination.

The manufacture of the semiconductor has two final processes, an electrical test and assembly. A computer driven test system inspects the chips for functionality and marks chips that have failed with ink. A diamond saw then slices the processed wafer into single "chips", discarding the failed ones. The chips are then assembled with contact leads and wires and sealed in a plastic coating for protection.

2. Semiconductor Product Classifications

Since the invention of the first semiconductor, many different types of circuits have been formed in silicon (and other materials) and just as many classifications have been used to describe them. Semiconductors are often classified by the technology used in the fabrication process or by their functional breakdown as electronic components. It is the latter classification, by function as electrical component, which will be used in this analysis.

Three major divisions of function are used in the description of semiconductors: discrete components, integrated circuits, and special purpose devices. Discrete components are devices such as transistors, rectifiers and diodes. The integrated circuit is the fastest growing and major product of the semiconductor industry. The integrated circuit includes two major product areas: microprocessors and memories. Microprocessors can be divided into micro-control units (MCUs) and micro-processing units (MPUs). Integrated circuit memories can be further divided into random-access memories (RAMs) and read-only memories (ROMs). Special purpose devices are exactly as they sound, manufactured to meet special needs. The term, application specific integrated circuit (ASIC), refers to these special purpose devices. Many of the semiconductors used by DoD fall into this latter category. (OECD, 1985, pp.10-11)

The distinction of the different classifications of semiconductors is tedious, but the functional difference, and differences in the manufacturing process created by those functions, play a critical role in understanding the marketplace. The breakdown of integrated circuits is especially important. Microprocessors are a logic chip which incorporate the central processing unit of the computer on a single chip. The circuits of microprocessors are complex as compared to memory chips. RAM chips contain the usable memory of the computer and are a series of identical patterns throughout the chip. RAMs can be further divided into dynamic (DRAMs) and static (SRAMs) devices. RAM chips contain memory that can be written to and read from many times, while ROM chips are memories that can be read many times but written to only once . ROM chips can also be categorized into erasable-programmable (EPROMs) and electrically-erasable (EEPROMs) memories. The circuits in ROM chips tends to be more complex than circuits used in RAM devices, depending on the desired use.

Semiconductors can also be made from materials other than silicon. The most recent research involves combining elements from part III and part V of the table of elements; these materials are referred to as III/V compounds. The most promising of the compounds is Gallium Arsenide (GaAs). Use of these materials often results in much higher operating speeds and resistance to radiation. Figure 1.3 breaks down the different classifications of semiconductors into categories representative of their phase in the product life cycle (California Technology Stock Letter, 1990, p.4).

3. Relevance of Technology

Having an understanding of basic semiconductor manufacturing technology is useful in grasping the nature of the market. The production of semiconductors is truly "high -tech". Research and development plays a large part in the relatively near term success of firms in the industry. When major discoveries are made, they are often directly translated into competitive advantages for the firms who have access to this new technology, and the manufacturing technology is advancing at a rapid rate. To produce the next generation of memory chips, sub-micron resolutions will be necessary. Goals of 0.50 micron circuit widths will be reality in the near future. For comparison, the width of a human hair equals approximately 100 microns, and 0.50 microns is equal to the wavelength of green light. The physics involved at these small levels changes, and even incremental improvements in

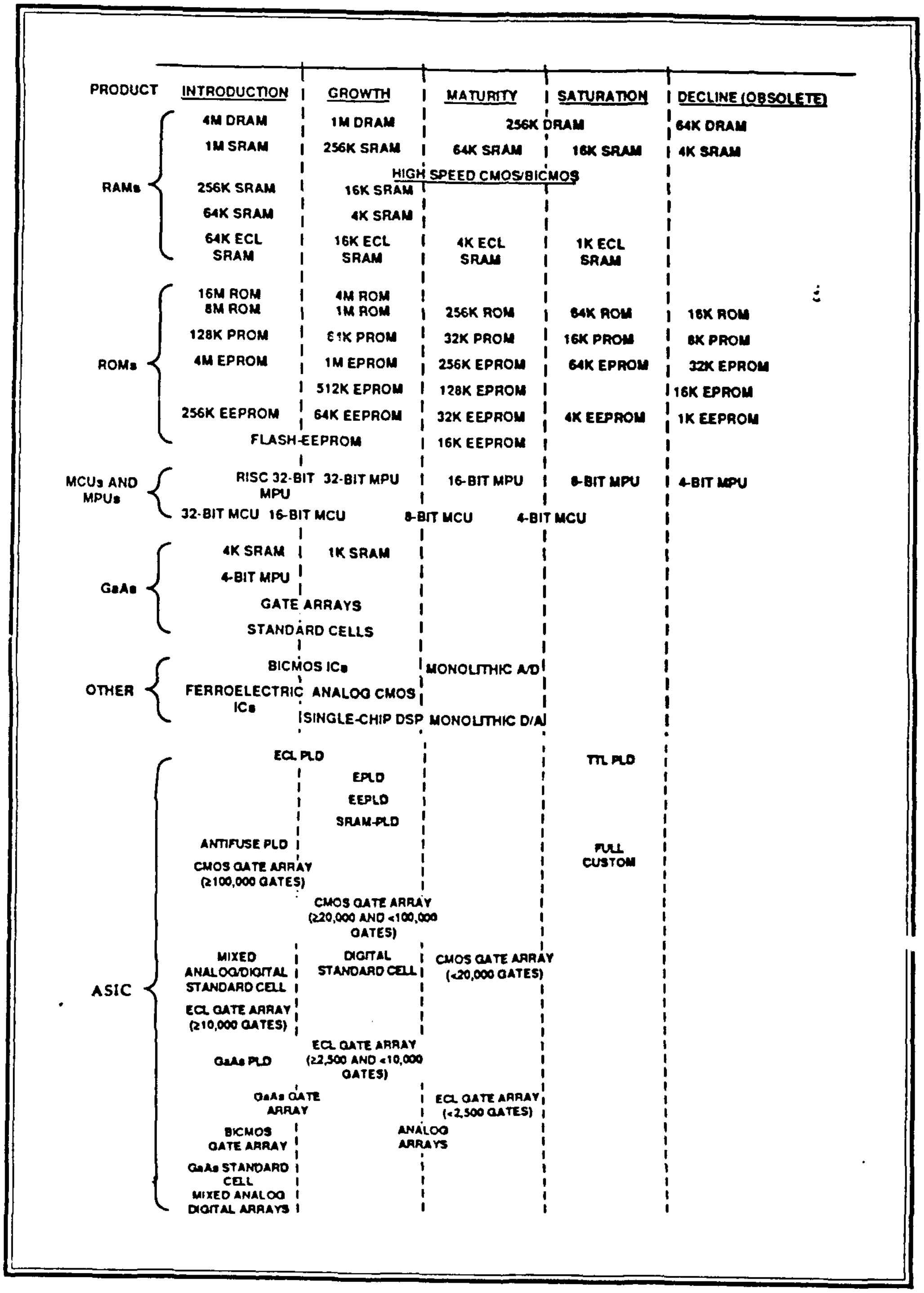

Figure 1.3 Product Life Cycle of Semiconductors

resolution require a great deal of effort. Once this technology is lost, it is not easily regained. (Brueck, 1990)

D. THE SEMICONDUCTOR MARKETPLACE

Our previous discussion has eluded to the importance of semiconductors in the worldwide market for electronics, but what firms make up the manufacturing industry? Table 1.1 lists the world's top 10 semiconductor producers based on their 1989 revenues (San Francisco Chronicle, 1990, p. c4). American captive producers are not included in the Table because the level of their production of semiconductors is held closely by the corporations.

TABLE 1.1 THE WORLD'S TOP TEN SEMICONDUCTOR MAKERS

Company	Country	1989 Revenues (in billions)	% Change From 1988
NEC	*Japan*	$4.96	9%
Toshiba	*Japan*	4.88	11
Hitachi	*Japan*	3.93	12
Motorola	*United States*	3.32	9
Fujitsu	*Japan*	2.94	13
Texas Instruments	*United States*	2.78	2
Mitsubishi	*Japan*	2.62	14
Intel	*United States*	2.44	4
Matsushita	*Japan*	1.87	-1
Philips	*Netherlands*	1.69	-3

The market for semiconductors continues to grow, and 1990 revenues are estimated at approximately $50 billion. Integrated circuits make up the majority of that market, accounting for $41 billion in 1990 sales. Figure 1.4 shows the trend in worldwide sales since 1982.

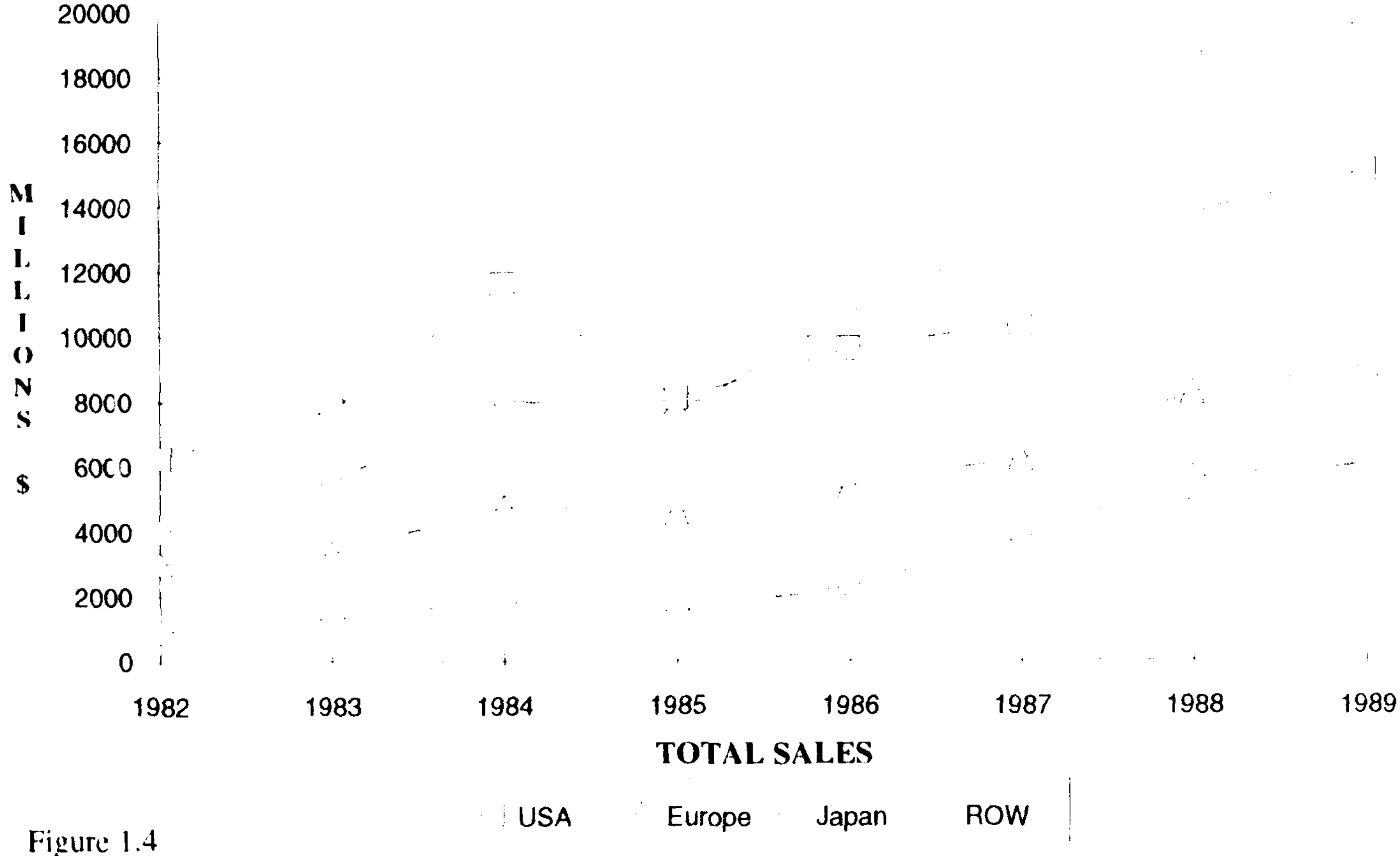
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
MILLIONS $
1982
1983
1984
1985
1986
1987
1988
1989
TOTAL SALES
USA
Europe
Japan
ROW

Figure 1.4

II. INDUSTRY VIEWPOINT

As noted in the first chapter, semiconductors and their impact on electronics play an important role in providing the "force multiplier" effect in today's weapon systems. National defense can also be framed as economic strength. A strong defense cannot be maintained without a vibrant economy to support it. Ian Ross, president of AT&T Bell laboratories and chairman of the National Advisory Committee on Semiconductors (NACS), voices the concern of many:

> Semiconductors are the heart of sophisticated electronic guidance systems and other vital elements of modern weaponry. In order to maintain a strong national defense we need a domestic semiconductor industry second to none. (Leopold, 1989, p.11)

In this chapter, the views and opinions presented are those of the semiconductor manufacturers and other knowledgeable individuals in this field of study. An analysis of the validity and strong-points of their viewpoints will be presented later in the thesis.

A major change has occurred in the perception and outlook for American semiconductor makers over the past decade. At the beginning of the decade, semiconductor manufacturers, along with other high growth electronics industries like personal computers, were hailed as the great success stories of the free market system. Now the industry portrays itself as one under excessive pressure from the fierce competition of foreign firms (The Economist, 1988, p.65). Ironically, it was competition that was hailed as making semiconductor manufacturers great just ten years earlier.

This decline in market share comes when the industry should have been enjoying good times. During the mid 1980s, the worldwide market was growing at a 30 percent annual rate. Growth in the market still remains moderately strong today, at approximately 10 percent (Electronics, 1990, p.82). American firms' share, however, continues to decline. American semiconductor manufacturers currently have 35 percent of the world market for semiconductors, down from 37 percent in 1989. Japanese firms, in contrast, control 51 percent of the market and their share continues to grow. This dramatic change is shown in Figure 2.1. Contrast this position with America's 58 percent share of the global market in 1980, when Japan controlled just 28 percent of the market. The erosion of America's market share to other competitors is demonstrated in Figure 2.2. This is not the only bad news. Japan has been able to maintain approximately 90 percent of its domestic market, while Asian/Pacific manufacturer's global market share, not including Japan, has grown at a pace four times the worldwide average over the past few years (Goldman, 1990, p.8). The market share of the Japanese market is shown in Figure 2.3. With this trend continuing, it is easy to understand American manufacturer's cries for help and protection.

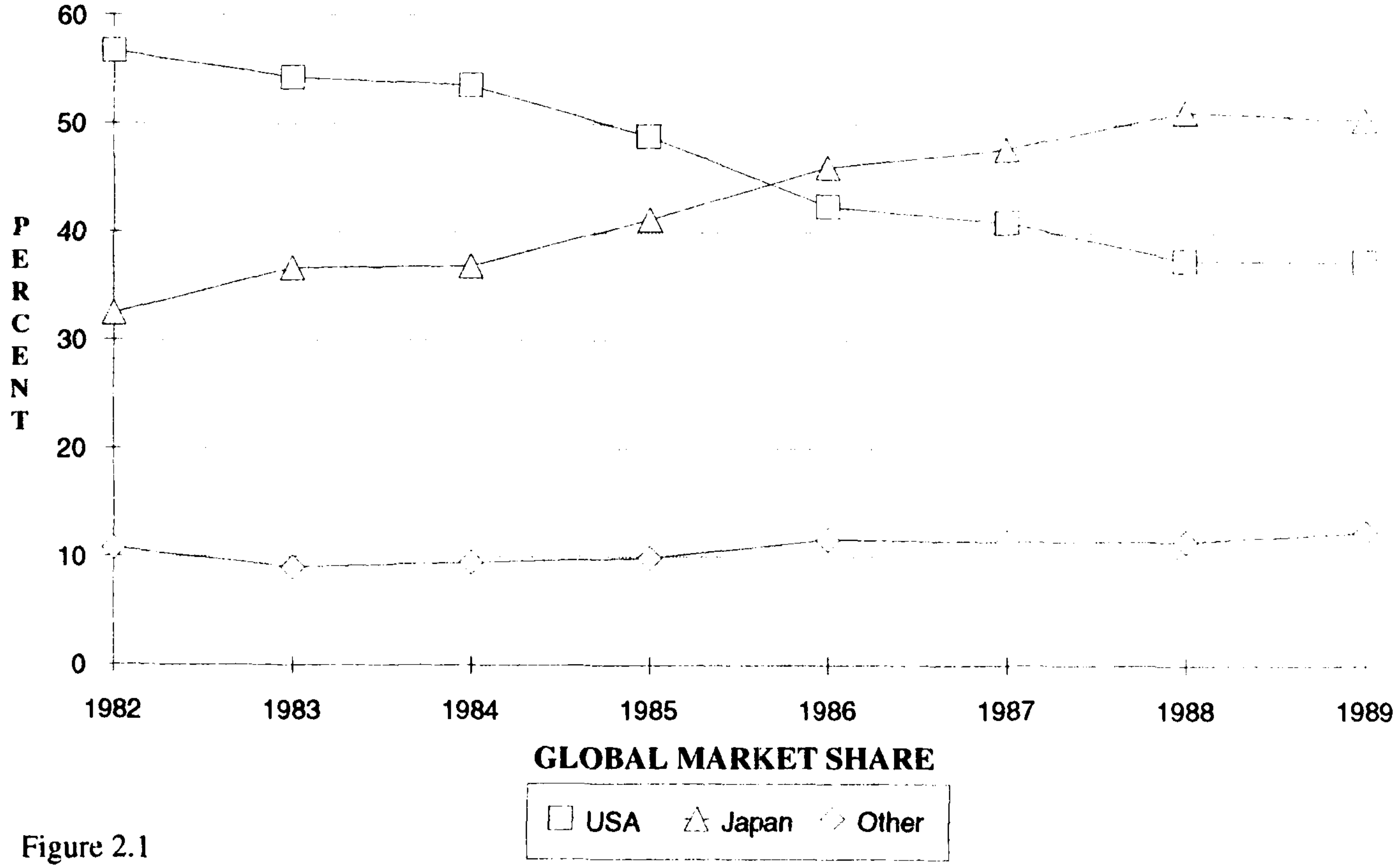
60
50
40
30
20
10
0
PERCENT
1982
1983
1984
1985
1986
1987
1988
1989
GLOBAL MARKET SHARE
USA
Japan
Other

Figure 2.1

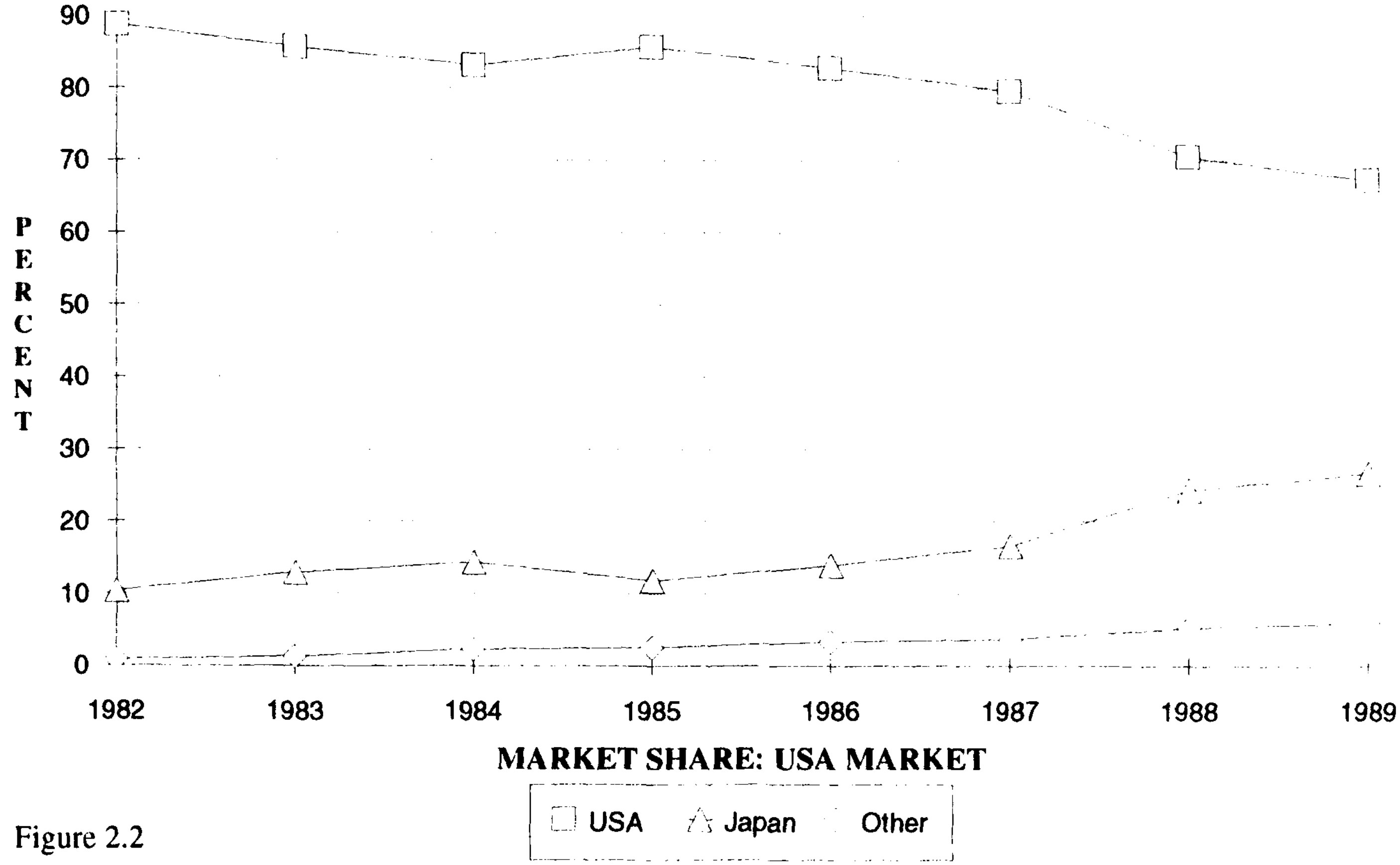
90
80
70
60
50
40
30
20
10
0
PERCENT
1982
1983
1984
1985
1986
1987
1988
1989
MARKET SHARE: USA MARKET
USA
Japan
Other

Figure 2.2

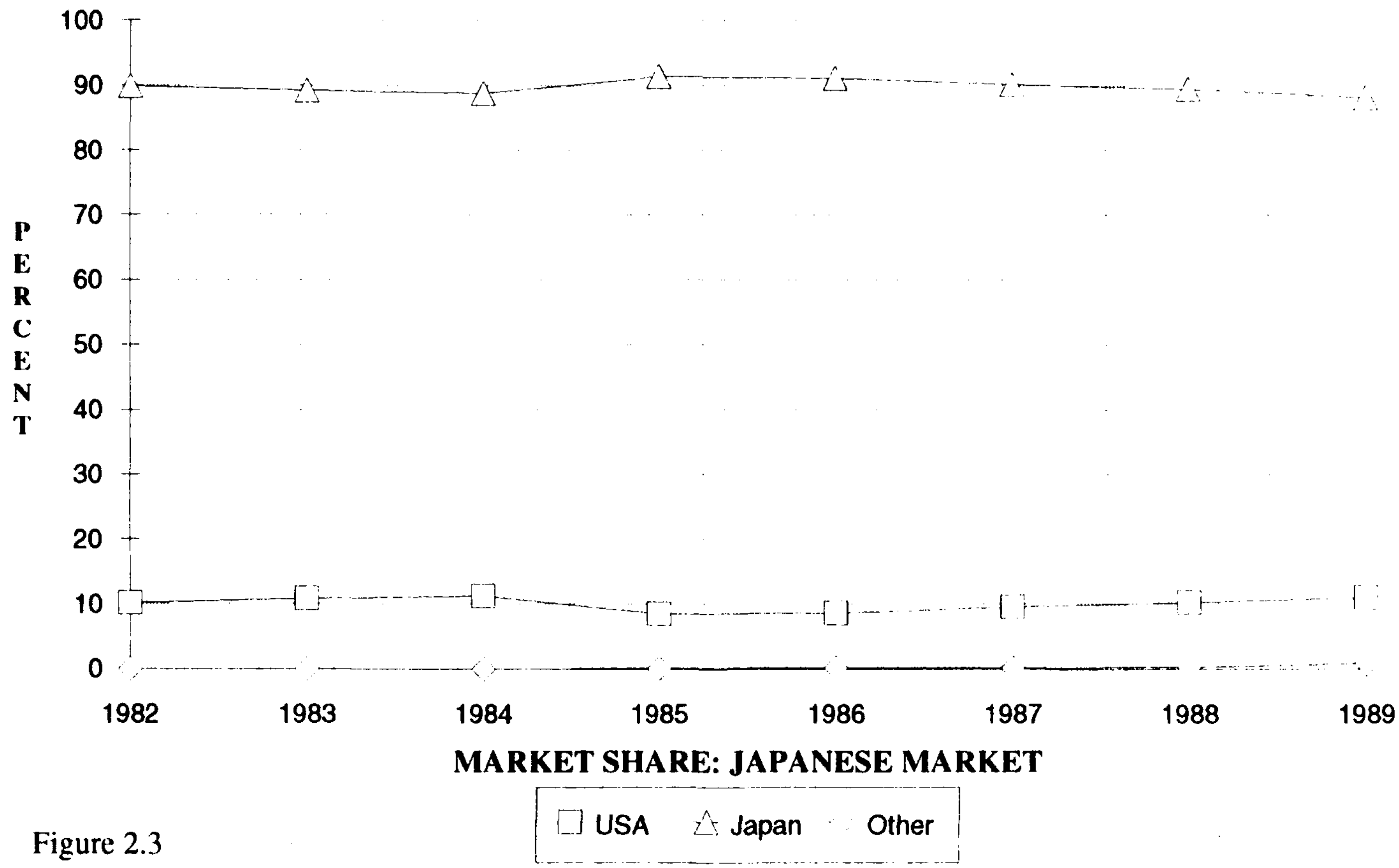
100
90
80
70
60
50
40
30
20
10
0
PERCENT
1982
1983
1984
1985
1986
1987
1988
1989
MARKET SHARE: JAPANESE MARKET
USA
Japan
Other

Figure 2.3

A. KEY EVENTS IN THE SEMICONDUCTOR MARKETPLACE

A look at some key events over the life of the industry may shed some light on the ongoing competition between American and Japanese semiconductor producers.

- 1956, Shockley Semiconductor founded and the commercial semiconductor industries begin in America and Japan.
- 1957, MITI passes Extraordinary Measures Law for the promotion of the electronics industry.
- 1959, Jack Kilby and Robert Noyce co-invent the integrated circuit and Japan targets computer industry as a high priority.
- 1960, Japan restricts sales of IBM computers and forces IBM to license 15 basic patents to Japanese electronics companies.
- 1960-1970, Japan limits Texas Instruments to 10 percent share of the Japanese market while excluding Motorola from the market entirely.
- 1970, 1K DRAM introduced by Intel
- 1971, Intel invents the microprocessor and EPROM technology is introduced.
- 1972, Japan agrees to remove formal trade restrictions on electronics products.
- 1975, Japan removes formal trade restrictions under the 1972 agreement.
- 1977, Programmable logic technology introduced.
- 1978, Japanese 16K DRAMs enter the marketplace.
- 1979, Japanese capture 40 percent of the 16K DRAM market.
- 1980, Toshiba introduces 64K DRAMs six months ahead of American producers.

- 1981, Nippon T&T introduce prototype 256K DRAM; American firms have 57 percent of the global semiconductor market while Japan holds 33 percent.
- 1983, Japan surpasses the U.S. in total absolute investment in semiconductor technology while MITI encourages Japanese companies to purchase more U.S. manufactured chips.
- 1985, Japanese firms slash DRAM and EPROM prices; 256K RAMs enter the market and every American company except TI and Micron abandon the DRAM business.
- 1986, Japan signs semiconductor trade agreement limiting exports of DRAM chips to the U.S., after allegations that Japanese firms "dumped" DRAMs into the U.S. market the previous year.
- 1987, SEMATECH, a semiconductor manufacturing research consortium is founded in the United States.
- 1987, April, President Reagan levies $300 million in sanctions against Japanese products for non compliance with 1986 trade agreement.
- 1987, November, all remaining sanctions against Japanese producers are lifted.
- 1989, European Community (EC) set specific criteria to determine if chips are EC made; EC prepares to levy tariffs against all non-EC chips imported into Europe.
- 1990, American companies share of the global semiconductor market falls to 35 percent while Japanese firms control 51 percent.

American producer's concern is voiced by venture capitalist Arthur Rock, known for helping build Silicon Valley: "my great fear, is that some day we will wake up and the Japanese companies will say they are sorry and cannot supply us with the necessary semiconductors to make our computers because they need them for their own production." (Clark, 1990, p.c1)

B. THE IMPACT AND IMPORTANCE OF DRAMs

After what industry officials viewed as "dumping" of DRAMs by the Japanese in 1985, all but a few American merchant companies gave up on the production of DRAM chips. However, captive producers continued to make memory chips for their own use. According to Dataquest, American withdrawal from the DRAM market is the key reason for its large loss of market share in semiconductors (Rice, 1990, p.1f). Asian/Pacific intrusion into the marketplace can also be attributed to American companies abandonment of the DRAM market (Goldman, 1990, p.8). Figure 2.4 illustrates this change. Since the U.S. and Japanese agreement not to sell DRAM chips below cost, one American firm has reentered the market. Today, three American firms continue to produce DRAMs in the United States for sale in the open market: Texas Instruments, Motorola, and Micron Technology (Rice, 1990, p.8f).

DRAMs constitute the largest single element in the semiconductor industry. In 1990 they are expected to reach $8.8 billion in sales, increasing to approximately $14.9 billion by 1993. DRAM production technology tends to be at the more mature end of the technology spectrum. In contrast, the production of microprocessors and specialty chips fall into the more innovative end of the technology spectrum. Japanese producers dominate this mature production technology with over 70 percent of the worldwide DRAM business.

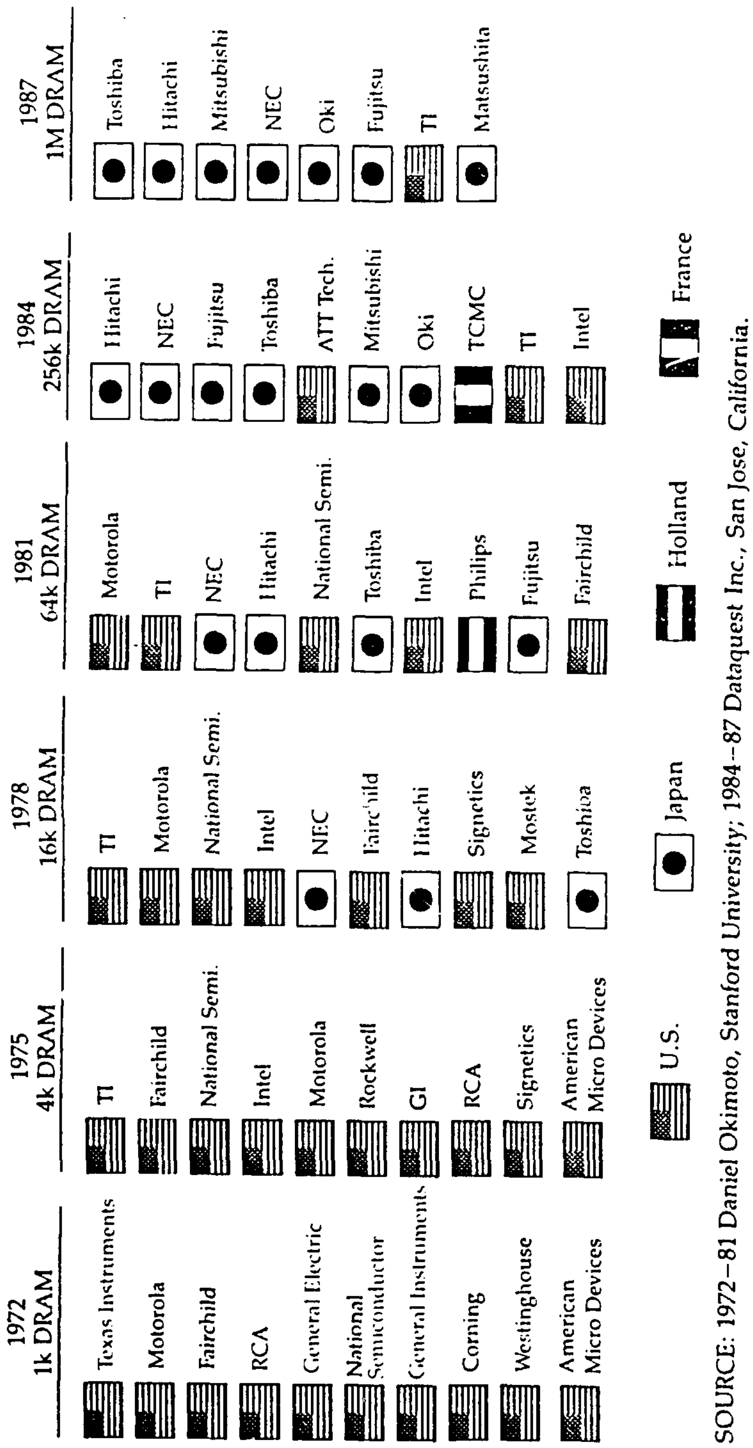

Figure 2.4 DRAM producers: 1972-1987

DRAMs have been referred to as the "technology drivers" within the industry because producers and designers of DRAMs can often exert influence over the development of other electronic systems. DRAMs, and other memory circuits, are crucial to the testing of manufacturing technology. Even in GaAs semiconductor production, where memory is not a large factor, the production of memory circuits is critical in detecting problems in the manufacturing process. The production of memory circuits duplicates millions of identical patterns on the chip material. The production of processors, and other semiconductors, are complicated patterns where the causes of problems are more difficult to isolate between manufacturing and design. (Prabhakar, 1990)

DRAMs are not only a test-bench for future technologies, they also provide much needed revenue to support on-going research. Future DRAM growth will be fueled by the ever increasing demands for memory use by next generation applications (SIA DRAM market facts). DoD's appetite for DRAMs and other memories may also increase as reliance on processing battlefield information grows in importance. Improvements in military information technology, and the increased military capability provided by improved data collection and management, will have more of an impact in future military potential than increasing the lethality of individual weapon systems (Gliksman, 1990, p.39). This information driven revolution will permit the replacement of firepower with brainpower, increasing DoD's reliance on the semiconductor and electronics industries.

C. AMERICAN STRENGTHS

While America's share of the total marketplace has declined, American companies still have a firm hold on some segments of the semiconductor market. Production of microprocessors and specialty chips are still considered an American strong-point. According to Andy Grove, chief executive of Intel Corporation, "the only thing that's American in those products [notebook and laptop computers] is software and microprocessors." (Clark, 1990, p. c1) If American producers are not careful, however, they may discover the Japanese and other foreign producers also making inroads into this segment of the marketplace. MITI is supporting a move by Japanese producers to get out of low added-value memory devices and into more lucrative advanced microprocessors. Microprocessors are not only more valuable, they require additional proprietary circuits to support them (The Economist, 1989, p.76).

D. ROOT CAUSES OF THE INDUSTRY DECLINE

What forces have caused American firms' rapid decline in market share? The decline in America's ability to compete in the DRAM market may not be the only force at work in this pattern of trade. For example, much of the reduction in market share can also be attributed to the dollar's fall against the yen (The Economist, 1988, p.65). The National Advisory Committee on Semiconductors (NASC) breaks down what it considers the root causes of America's decline in this critical market into three broad categories: the business environment, the market, and the state of technology. (NACS, 1989, pp.17-21)

1. The Business Environment

The NACS emphasizes that the differences in the business environment between the United States and its major competitors have worked to the advantage of foreign producers and to the detriment of the American industry. The major differences being the availability of low-cost capital, supportive industry practices of foreign producers, failure of the U.S. school system to provide trained workers, and difficulty in enforcing U.S. legal rights abroad.

The most serious disadvantage, as stated by the NACS, is the lack of low-cost capital for American firms. As already noted, future competitiveness in semiconductors relies heavily on research and development. A lower cost of capital allows foreign competitors a lower risk in investment decisions, enabling them to take a longer range focus toward the marketplace. The lower cost of capital also helps competitors weather downturns in the business cycle.

It is also felt by the industry that foreign competitors benefit from favorable industry policies and the support of their national governments. Policies such as closing markets to outside competition and coordinating research and development have given the impression of an unfair advantage. Compound these market conditions with an American education system that emphasizes education of students in theoretical disciplines, but neglects manufacturing training. This reinforces the impression of the un-level playing field.

The final cause of decline in the business environment exists in the lack of enforcement of U.S. copyrights and patents overseas. Japan required the licensing of key semiconductor technologies in the 1960s and 1970s in order to allow TI and IBM access to their domestic market (SIA, 1989, p.9). This biased legal situation is compounded by strict U.S. antitrust legislation regulating cooperation among American firms and limiting the formation of large semiconductor conglomerates in the name of free trade.

2. The Market

The NACS notes that the fundamental problem in market conditions facing American producers is the transfer of the electronics customer base to the far east. It has already been emphasized that semiconductors are an integral part of the "food chain" of modern electronic technology. Just as the production of memory chips has migrated to Japan, so has most of the world's electronics industries. The shift in the production of consumer electronics is probably the most striking example. With a large portion of the potential customers for American semiconductors being overseas, the problem of American firms recapturing market share is compounded. If the design of electronic systems is done in Japan, it should not be surprising that they call for Japanese components in the assembly of the final product.

3. The Technology

Semiconductors are high technology products and require a substantial amount of research and development to produce. A large investment in people, technology and facilities is required to maintain a competitive posture. Japanese producers have been able to out-invest their American counterparts. In 1983, they surpassed the United States in total investment in semiconductor technology (SIA, 1989, p.4). This is not the only area where Japan has outperformed American firms; American firms have not supported joint research in the early stages of process and material development. Today, the majority of semiconductor manufacturing equipment is owned by the Japanese. A representative from Nikon was asked during a recent meeting of the Semiconductor Equipment Manufacturers Industry (SEMI) in Hawaii when the latest generat on of photolithography equipment would be made available to American firms. The response from Nikon was "when appropriate". (Robertson, 1990, p.10) The formation of SEMATECH is an effort to improve the manufacturing technologies available to American industry while maintaining the competitive separation of firms needed by the free market system.

E. INDUSTRY RECOMMENDATIONS FOR IMPROVEMENT

"[T]he best way to assure American industry [and the Department of Defense] of getting the most advanced state-of-the-art technology is to develop it ourselves." (Robertson, 1990, p.10) The focus of the NACS recommendations are an effort to improve the competitive position of U.S. firms so they will be in the position to do just that, continue developing state-of-the-art technologies. The NACS position is surprisingly less protective than would be expected. They present their recommendations in response to the three areas described above: market improvements, changes to the business environment, and emphasis on new technology.

1. The Market

The NACS recommendations focusing on market improvement revolve around rebuilding the U.S. consumer electronics industry. If the consumer electronics industry can be revived, it will improve the customer base available to the semiconductor industry while slowing the flow of consumer electronic ownership and manufacturing to eastern pacific countries. The specific recommendations include establishing a consumer electronics capital corporation and enforceing fair trade practices. Other recommendations aimed at improving the market situation include establishing standards for electronic products and accelerating fiber optic service to the home.

2. **The Business Environment**

Recommendations voiced to improve the business environment revolve around improvements in the educational system, trade law reform, improvements in the protection of intellectual property, and capital formation incentives. Recommendations to improve the educational system emphasize the need to train workers that have technical backgrounds as well as an increased emphasis on teaching for technical and engineering degrees at the advanced level. Technical expertise is stated as being the lifeblood of the industry; without competent and knowledgeable personnel, the evolution of new generations of products will be impossible. Trade law reforms include emphasis on obtaining full access to foreign markets while continuing anti-dumping regulations and the protection of intellectual property.

Perhaps the most significant recommendations to improve the business environment involve incentives for capital formation. NACS presents numerous suggestions that would improve the availability of low-cost capital so desperately needed for this industry to remain competitive.

Some of these recommendations include: reinstating the investment tax credit, reducing the capital gains tax, making the research and development tax credit permanent, and increasing personal savings incentives. Reducing the federal deficit is also recommended to slow the flow of foreign capital into the United States, which in turn fuels the trade deficit.

3. The Technology

To help increase the technological position of the semiconductor industry, the NACS recommends increased federal support of research and development through a variety of means. This support should continue to be provided through SEMATECH and centers of academic excellence, as well as continued funding of research in very high-speed integrated circuits by DoD and the Department of Energy (DoE). Enhancing x-ray lithography through support provided from DoE is also recommended.

F. CONCLUDING VIEW

To sum up the basic views voiced by the NACS and the semiconductor industry, John Armstrong, vice president for science and technology at IBM, said that four things can be done by industry and government to reverse the trend toward a declining U.S. semiconductor market share:

- Increase the availability of capital, including a tax cut for total spending on research and development.
- Extend the 1984 National Cooperative Research Act to include joint production.
- Support the semiconductor infrastructure through increased funding of SEMATECH.
- Improve the efforts to produce well-educated workers.

III. ECONOMIC THEORY AND VIEWPOINT

Since the importance of the semiconductor market to the U.S. economy and defense has been established, and the views and recommendations of industry members have been presented, it will be useful to examine economic theory and identify the underlying forces at work in this pattern of trade.

Basic economic theory supports the view that gains can be made through the conduct of free trade. Two nations can improve their economic position by producing and trading the goods at which they are most efficient for those goods which are relatively more costly for them to produce.

What factors influence this pattern of trade? In determining the direction of trade flows, relative efficiency and costs in each country are the critical factors. Vernon gives us some insight into this situation in his article "International Investment and International Trade in the Product Cycle." (Vernon, 1966, p.190) Vernon's model contends that the location of producers and the mix of inputs are directly influenced by the product's stage of life. Vernon divides product life into three different categories: new product, maturing product, and standardized product.

Vernon's model is based on a few assumptions about entrepreneurial opportunities and the United States market.

Entrepreneurial opportunity, and the ability to recognize and respond to this opportunity, is a direct result of the ease of communication. The relative ease of communication is a function of geographical proximity. Vernon (1966, p.192) emphasizes that "the United States market offers certain unique kinds of opportunities to those who are in a position to be aware of them." The United States consumers have an average income that is higher than other developed countries, and the labor costs and unrationed capital in the United States are high as compared to other markets. These factors influence where an entrepreneur will develop and produce a product, and in which markets those products will be sold.

A. NEW PRODUCTS

These assumptions lead to the hypothesis that American producers will be the first to notice and exploit the opportunity provided by both the relatively high-income and the natural incentives for labor saving products in the United States. It also leads to the conclusion that these products will be produced in the United States. Vernon (1966, p.194) points out that this assumption is not "self-evident." Least cost theory asserts that goods are produced where their production and transportation costs are minimized. However, Vernon concludes that "...the early producers of a new product intended for the United States market are attracted to the United States location by forces which are far stronger than relative factor-cost and transport considerations." (Vernon, 1966, p.194) Some of those stronger forces may be related to the unstandardized nature and design of the developing product.

As products are developed, they tend to be less standardized than those in full production. The mix of inputs and final specifications cover a wide range of possibilities. This unstandardized design "...carries with it a number of locational implications." (Vernon, 1966, p.195) Producers tend to be concerned with the degree of freedom they have to change their product or its inputs. Demand for the product is relatively insensitive to price due to the high degree of product specialization and a monopolistic situation in the early stages of production. Furthermore, the need for fast communication between the producers, consumers, and possibly competitors is relatively high. These implications point to the conclusion that producers of a new product will want to be close to the market for which the product is intended.

B. MATURING PRODUCT

As the demand for the product increases, the degree of standardization in the product increases. Producer-supplier relationships also increase and become more formal. Prices and location of inputs become more fixed and predictable, and competition for production of the product increases as others enter the market. Factor costs and the efficiency of production play a more important role in the continued success of the product. The need for flexibility in product design declines while standards of production and economies of scale become more important considerations.

This changing situation has locational implications. "If the product has a high income elasticity of demand or if it is a satisfactory substitute for high-cost labor, the demand in time will begin to grow rapidly in relatively advanced countries...." (Vernon, 1966, p.197) If the demand in these more advanced countries continues to rise, eventually the producers will ask themselves if it is worth the risk to establish production facilities in this foreign country. When the marginal production costs plus the transportation costs of products produced in the United States is greater than the estimated average cost of production in the advanced country, United States producers will seriously consider investment in the foreign country. (Vernon, 1966, p.197)

Once production facilities are established in a foreign country, Vernon notes that a different group of forces are set in motion. The "...production cost differences between rival producing areas are usually differences due to scale and differences due to labor costs." (Vernon, 1966, p.198) Differences in the international firm's cost of capital between these alternative locations might also be important, particularly in areas where labor cost differences are small. This foreign location also provides an opportunity to service third-country markets. And if the factor cost differential becomes great enough, then "...exports back to the United States [market] may become a possibility as well." (Vernon, 1966, p.200)

C. STANDARDIZED PRODUCT

As one might expect, in the advanced stage of the product's production, the factor cost savings in foreign locations, particularly from labor, provides a competitive advantage to the firm. An established market and production process helps reduce the risks associated with overseas production. As the production process becomes more standardized, factor costs become increasingly important. The establishment of production facilities in less-developed countries then becomes a possibility.

Vernon points out some economic characteristics of products which may be benefitted by overseas production, at times where capital cost differences across countries are negligible.

> Their production function is such as to require significant inputs of labor; otherwise there is no reason to expect a lower production cost in less-developed countries. At the same time, they are products with a high price elasticity of demand for the output of individual firms; otherwise, there is no strong incentive to take the risks of pioneering with production in a new area. In addition, products whose production process did not rely heavily upon external economies would be more obvious candidates than those which require a more elaborate industrial environment. (Vernon, 1966, p.203)

To summarize Vernon's basic hypothesis, the United States will export high-income and labor-saving products in the early stages of production. As the production process matures, production of these products will migrate overseas, with the United States eventually importing the goods (Vernon, 1966, p.201). Assuming these products fit the characteristics described above, the production facilities could also migrate to less-developed countries.

Vernon's article also highlights some more subtle observations of international trade and investment. The Leontief paradox, the fact that the ratio of capital to labor in the United States exports was lower than the like ratio of United States production which had been displaced by competitive imports, is explained in Vernon's model by the differences in the product life. In early stages of production, there is less standardization so the manufacturing process requires a greater input of skilled labor. As the manufacturing process matures, the risk of investment in capital intensive facilities overseas is reduced. "As a result, the production process relies relatively heavily on labor inputs at a time when the United States is in an export position; and the process relies more heavily on capital at a time when imports become important." (Vernon, 1966, p.202)

Vernon asserts that trade and international investment will be dependent on the stage of the product life and some basic economic characteristics, such as the product's price elasticity of demand. What other factors might influence international trade? Hilke and Nelson explored a list of microeconomic factors that are often linked to the United States trade deficit. They attempted to isolate important factors which impact the level of the trade balance through the use of a complex regression model. Hilke and Nelson also reviewed some macroeconomic factors that influence trade and summarized their impact. From their study some interesting policy conclusions can be drawn.

D. MICROECONOMIC FACTORS

Seven specific microeconomic explanations for the change in the United States trade position were evaluated by Hilke and Nelson (Hilke & Nelson, 1988, p.12):

- The High Labor Cost Explanation.
- The Union Work Rules Explanation.
- The Foreign Government Trade Practices Explanation.
- The OPEC Cartel Explanation.
- The Declining R&D Explanation.
- The Inadequate Investment Explanation.
- The Antitrust Explanation.

For each of these explanations, Hilke and Nelson "...statistically test[ed] for the presence of shifts in the relationship between U.S. trade patterns and market characterist s that are associated with each explanation." (Hilke & Nel n, 1988, p.5)

1. High Labor Costs

The high labor costs explanation suggests that rapid increases in United States wage rates during the 1960s and 1970s eroded the manufacturing competitiveness of American producers. The rate of increase, however, is dramatically reduced when adjusted for the value of national currencies. On average, American "...compensation per hour, when adjusted for the change in output per hour, has been about average for industrialized countries during the 1975-1983 period." (Hilke & Nelson, 1988, p.6)

2. Union Work Rules

The union work rules explanation asserts that union work rules and practices have reduced the productivity of the American worker and hurt the competitiveness of American firms, thereby encouraging imports. The increase in output per hour in the U.S. was one of the slowest noted by Hilke and Nelson. However, this slow in U.S. output per hour can be attributed to many explanations besides union work practices. For example, it can be attributed to higher income, providing firms more incentive to move to service related industries, and higher use of developing technologies.

3. Foreign Government Trade Practices

The foreign government trade practices explanation notes that foreign firms have increasingly received assistance from their governments to enter specific U.S. markets. The explanation notes these practices have put American firms at a disadvantage. Hilke and Nelson point out that while this targeting does occur, it is not known how effective or widespread the practice has become, and assistance to domestic firms from the U.S. government may have offset the effect of these practices.

4. OPEC Cartel

The OPEC Cartel explanation asserts that U.S. manufacturers use large amounts of energy relative to foreign firms. Thus, increases in oil prices, specifically in the late seventies, hurts U.S. manufacturers more than foreign manufacturers. However, throughout the 1980s energy prices were relatively low, without a corresponding reduction in the trade balance. This effectively negates this argument.

5. Declining R&D

The declining research and development explanation argues that since R&D expenditures declined throughout the seventies, the R&D advantage that U.S. firms have enjoyed since World War II has been eroded. Hilke and Nelson note that there is some evidence to support this argument. There was a reduction in U.S. R&D expenditures in relation to GNP in the late seventies. At the same time, Germany and Japan increased their expenditures. However, it is not clear how this reduction is related to U.S. trade performance. Hilke and Nelson also note that this "dip" only represents a change in the increase in knowledge that will be derived from research, not a change in the stock of cumulative knowledge. If the decline in R&D is sustained for a long period of time, the effect might be felt in the balance of trade.

6. Inadequate Investment

The inadequate investment explanation blames U.S. tax policy for the lower savings rate and poor investment incentives that exist in the United States. These tax policies have impacted on the U.S. capital base, making investment in newer technologies more difficult for American firms. As Hilke and Nelson point out, only Japan and Canada have higher rates of capital formation. Even though these countries have a greater capital formation rate than the United States, the U.S. still has higher rates than many other countries. Even though many industrialized countries have accelerated their capital formation relative to the U.S., our capital stock is large and it will be some time before the "gap" narrows.

7. Antitrust

The antitrust explanation asserts that American antitrust laws impact on U.S. firms' ability to join forces and pool resources. While it is true that U.S. antitrust laws do exist, it is not clear how they might impact international trade. Hilke and Nelson site empirical evidence that U.S. firms and plants are larger than their foreign counterparts.

8. Summary of Microeconomic Findings

To summarize the microeconomic findings of Hilke and Nelson, some evidence is available to support these explanations but it is far from definitive. The noticeable change in the U.S. trade position cannot be explained on these factors alone. But Hilke and Nelson do point out some macroeconomic factors that have a more substantial impact on international trade.

E. MACROECONOMIC FACTORS

Two events that have occurred in the late seventies and early eighties point to strong macroeconomic influences at work in the balance of trade. The "...increase in U.S. aggregate demand relative to foreign aggregate demand and the increase in U.S. interest rates relative to foreign interest rates." Both these changes can be caused by the dramatic increase in the U.S. national debt. (Hilke & Nelson, 1988, p.1)

The macroeconomic forces at work are summarized by Hilke and Nelson as follows:

> The excess of spending over income provided a powerful expansionary fiscal policy while higher interest rates had to be used to attract foreign and domestic investors to

finance the growth of the debt. A relative increase in aggregate demand...is expected to lead to a trade deficit....A relative increase in U.S. interest rates can also lead to trade deficits by increasing foreign demand for U.S. financial assets. The link between financial flows that respond to interest rate changes and trade deficits is evident in standard balance of payments accounting relationships. (Hilke & Nelson, 1988, p.1-2)

Hilke and Nelson conclude that recent budget deficits, not weakening of industrial characteristics, have lead to the decline in competitiveness of U.S. firms. Their statistical evidence does not support the notion that microeconomic forces have impacted international trade to a large degree. Hilke and Nelson note that U.S. policy should focus on reducting the budget deficit rather than focusing on microeconomic factors. However, they also warn that their analysis is not "unqualified acceptance" of free trade policies. (Hilke & Nelson, 1988, p.144)

F. ECONOMIC CONCLUSIONS

Vernon notes that as technologies mature, relative factor prices become increasingly more important. Hilke and Nelson point out that macroeconomic policies, especially the growing budget deficit, have driven up interest rates in the U.S., making capital more expensive. Capital costs, as well as labor costs, are significant factor costs in Vernon's model, helping to determine the production location of mature technologies. The U.S. semiconductor industry has maintained its comparative advantage in high-technology products like microprocessors and specialty chips. The Japanese advantage is predominately in areas where the technology is relatively more mature, such as in the production of DRAMs and other memory devices. This observation is consistent with Vernon's product life-cycle theory, and the two trade models appear complimentary.

Trade patterns in semiconductors appear to be responding to factor price differences, consistent with the historic pattern, but the budget deficit may also influence the trade pattern in another way. Increased government spending, and the increased government borrowing to pay for the deficit, fuels aggregate demand in the United States. This increased aggregate demand causes imports in general to rise relative to exports, helping to support the historical trade pattern described above. In summary, based on the relative maturity of the technology involved in the production of DRAMs and other memories, it is not surprising to see countries that enjoy lower factor prices producing the majority of those goods in the global marketplace.

IV. ANALYSIS OF DOD'S ROLE IN SEMICONDUCTORS

Since the industry's viewpoint and concern has been established and an economic groundwork has been laid, a closer analysis of DoD's relationship to the semiconductor industry is now possible. First, the focus will be on DoD's concern within the industry, and second, the analysis will focus on what actions DoD should be pursuing to address those concerns.

A. DOD'S CONCERN IN THE SEMICONDUCTOR INDUSTRY

As previously discussed, the Department of Defense relies heavily on semiconductors to improve the capabilities of today's weapon systems. Approximately two percent of the cost of the F-4 Phantom aircraft was spent on computers and software, while the percentage spent on electronics for the F-15 fighter rose to 25 percent. This reliance on technology continues to grow. Today, 40 to 50 percent of the cost of the F-18 is spent on electronic components (U.S. Congress, 1987, p.28). Despite this growing reliance on technology, DoD accounts for less than ten percent of semiconductor sales in the United States and only three percent of the quantity (Dallmeyer, 1987, p.48). Since DoD's "business" alone cannot be expected to support the industry, national security questions arise when the domestic industry appears to be faltering.

DoD's concern over its dependence on advanced foreign technology manifests itself in two fundamental ways. First, DoD purchases sophisticated electronics from domestic suppliers and is concerned about maintaining a secure supply. Second, it relies on the industry to identify and exploit state-of-the-art technology in designing new weapon systems (U.S. Congress, 1987, p.29). This concern for a secure supply and access to advanced technologies leads to a third consideration, maintaining a strong industry and economy.

1. The Security of Supply

Concerns for a secure supply arise out of a possible dependence on foreign sources for semiconductors and new technologies. The extent of DoD's dependence on foreign sources is difficult to determine, and the exact percentage of weapons that contain foreign parts is not known (Dallmeyer, 1987, p.49). However, the Defense Science Board Task Force on Semiconductor Dependency stated that a "...significant fraction of chips used in the newest systems about to be deployed are either entirely made, or packaged and tested, abroad." (U.S. Department of Commerce, 1987, p.2) One of the more publicized dependencies for semiconductors is on the Far East, specifically Japan. The task force also noted that "...acquisition of specific devices or materials from foreign sources for defense applications is not a critical problem as long as the U.S. has the knowledge and resources to substitute domestic sources in a timely fashion should the supply of foreign products or technologies be interrupted." (U.S. Department of Commerce, 1987, p.3) Just how should this domestic source be maintained?

One possible answer to the threat of interrupted supplies is the stockpiling of foreign made semiconductors (Dallmeyer, 1987, p.52). The U.S. currently stockpiles many items for use in an national emergency. The stockpiling of semiconductors would allow the U.S. to have access to the semiconductors it needs to continue production of current weapon systems. However, the stockpiling of semiconductors raises other questions. For example, what level of supply should be maintained and how long will the crisis last? Will advances in technology make stockpiles obsolete before they can be incorporated in new weapon systems? (Carpenter, 1990, p.42)

One alternative to stockpiling that is often discussed revolves around DoD building its own manufacturing plants to produce the semiconductors it needs (U.S. Congress, 1987, p.29). This alternative has some severe shortcomings, however. It fails to address DoD's reliance on the semiconductor industry for innovation and advancing technology. The production solution addresses the supply problem but also ignores the strong possibility of cost overruns (Carpenter, 1990, p.49). In short, the establishment of government owned and run manufacturing facilities is not the most efficient solution to maintaining a secure supply of semiconductors.

Another possible solution to enhance the security of supply would be to designate domestic "captive" producers, like IBM, to act as back-up suppliers in a national emergency or mobilization (Dallmeyer, 1987, p.52). With DoD's requirements being relatively small, domestic captive suppliers should be capable of supporting DoD's needs in a crisis. IBM is considered one of the largest semiconductor producers in the world, even though all of their production is designated for its own use. It is reasonable to assume they can be relied upon to meet any critical shortages, should they occur.

A final point should be made regarding the security of supply. The likelihood that foreign suppliers will limit the quantity or quality of semiconductors to DoD is small. Even if one country should choose to restrict this supply, it is certainly unlikely that all foreign producers would do so at the same time. Foreign producers have a large incentive to supply the U.S. with semiconductors. For example, Japan has a constitutional limit on military spending and they rely heavily on the U.S. for their national defense. It is in Japan's best interest to supply extremely reliable high-technology products and ensure a continued U.S. defense presence in the region (Dallmeyer, 1987, p.55).

2. The Ability to Incorporate New Technology

An inherent problem plaguing program managers in DoD is the incorporation of the most advanced technology in their weapon systems. Many competing priorities, including time and money, force a developing system into production. Combine these difficult decisions with the long lead time of most weapon systems, and incorporating advanced technology becomes a non-trivial problem. Even when the most advanced technology is available to DoD, the technology must be perfected and meet scheduling "windows" in order to be incorporated in developing systems (Prabhakar, 1990). To illustrate the point, some of the most advanced technology has been incorporated into the B-2 Stealth bomber; however, the grand central station of its interlinked computer system is a black box based on a 16-bit microprocessor. By today's standards, the 16-bit microprocessor is already considered obsolete, except for performing all but the most routine tasks (Grier, 1989, p.36).

This concern is a very real one and demands a great deal of consideration. For DoD to continue producing the most advanced weapons in the world, it must have access to state-of-the-art technologies. When discussing the national security issue and technology, defining defense technology base becomes important. It can be described as "...the combination of people, institutions, information, and skills that provide the technology used to develop and manufacture weapons and other defense systems." (Moore, 1989, p.24)

Creativity and innovation have been the strong points of American industry for years, and these competitive skills have given DoD access to the best technologies in the past. However, a decline in the manufacturing expertise of American semiconductor producers raises the concern of continued access to advanced technologies in the future. Efforts have been focused on defense design expertise vice production and manufacturing technologies. This is the central concern of the semiconductor industry today. Industry feels that "although American basic research technology is virulent, manufacturing expertise continues to be the Achilles heal of the commercial and defense semiconductor technology base." (Moore, 1989, p.29)

While maintaining a strong manufacturing base is important, American semiconductor producers should rely on leveraging their strong points. The U.S. currently leads the world in highly creative technologies such as software engineering, applications technologies, and computer architectures (CSPP, 1990, p.25). DoD's efforts should be focused on maintaining and exploiting these traditional strong-points of the American industry. What is important is access to the technical knowledge necessary to produce state-of-the-art semiconductors. However, it is not important to restore American leadership in manufacturing the more mature technologies of DRAM production. This is a subtle but substantial difference.

Access to critical production technologies is important. However, the processes used to produce advanced chips is changing, and the technologies currently used in semiconductor manufacturing may not be appropriate for the chips introduced in the later 1990s (U.S. Congress, 1990, p.69). For example, optical lithography will be replaced by X-ray lithography and other technologies as resolutions continue to move into the sub-micron level. American research and development in process technology for advanced products is important to DoD's needs. This technological base can no longer be taken for granted. DoD's support for projects like SEMATECH, a manufacturing process research consortium for advanced memory chips, attempts to address those concerns. Concern over losing the technology base also leads to a more fundamental consideration, maintaining a strong industry and economy.

3. A Strong Industry and Economy

A strong economy is central to the national defense of the United States, and a strong semiconductor industry could be considered central to the technological superiority of American forces. However, careful considerations should be made when evaluating what support DoD should provide the industry in the name of national security.

American semiconductor strength should be focused on the production of emerging technologies. Concentrating on products which are in the early stages of their product life is important. Industry's concerns in this area are not totally unfounded. Japan and other semiconductor producers have a growing lead in the production of advanced memories. Large amounts of capital are being invested as Japanese firms strive to be first in the production of 64-megabit chips (Sanger, 1990, p.cl). Some of this production technology provides the ability to produce other advanced circuits, but not all. Production of simpler memory circuits at high volumes does not directly translate into the ability to produce advanced specialty chips at low volume, and the majority of the chips used by DoD are of this latter category.

As already noted, American strength lies in innovation and creative enterprises. It lags other countries in capital intensive technologies, such as large scale fabrication and manufacturing (CSPP, 1990, p.25). When considering the macroeconomic forces at work in our system of free trade, this situation should not be a surprise. The American semiconductor industry leads the world in most areas except in the production of the more mature technologies like memories. The value of this technology has already been established. However, DoD's focus should *not* be to help restore the American industry to its previous position of economic superiority in all areas of semiconductor manufacturing. The focus of DoD efforts should be on enhancing the areas in which the industry strength lies.

The discussion of maintaining a virile semiconductor industry with a focus on its strengths in innovation and engineering leads to the question of what role should DoD play to accomplish these objectives.

B. DOD'S ROLE IN THE INDUSTRY

First, history shows that protectionism is not the answer. Trade sanctions against foreign low-tech competition will not help domestic producers become more efficient. The higher DRAM prices that resulted after the trade sanctions of the late 1980s only had the effect of hurting U.S. electronics producers who were forced to purchase the more expensive chips. (The Economist, 1989, p.76)

A focus on high technology innovation should be the thrust of DoD and government policies. Maintaining the most advanced process technologies should be emphasized while creating an environment which supports the conduct of a strong, innovative industry. Three key success factors are critical to the competitiveness of U.S. firms in the computer industry: the business environment; the research, development and manufacturing relationship; and the people and culture of U.S. firms (CSPP, 1990, p.25).

1. Business Environment

Somewhat surprisingly, the majority of recommendations put forward by the NACS, and summarized earlier in the second chapter, fit nicely into the economic trade theory presented in the fourth chapter. An increase in factor costs in the U.S. has accelerated the movement of relatively more mature production technologies to areas with lower factor costs. It should be noted that Japanese producers are open to this economic pressure as well. As wages and interest rates rise in Japan, they will come under increasingly greater pressure from other manufacturing areas. Some of this competition can already be seen in the rise of the Asian/Pacific producers of semiconductors (excluding Japan). Improving the business environment in the U.S. entails actions that will help reduce the factor costs of domestic manufacturers.

The most substantial improvement in the business environment can be achieved by a reduction in interest rates and a corresponding reduction in the cost of available capital. The cost of capital can be reduced in a number of ways; the most effective would be a reduction in the size of the federal deficit. Increasing incentives for savings and possible changes in the tax system would also help to increase the amount of affordable capital available for investment in capital intensive industries.

Reduction of interest rates is not the only action that may improve the competitiveness of domestic producers. Continued pursuit of intellectual property protection, fair and open competition in foreign markets, and changes in domestic anti-trust legislation all play a part in the health of the U.S. semiconductor industry. Changes in anti-trust legislation may help to stimulate greater research cooperation among firms and encourage more vertical integration in areas where industry finds that these changes are appropriate. It has been assumed that large American "captive" producers do not sell their semiconductors on the open market for fear of unfair competition and discrimination charges. The large Japanese semiconductor producers do not come under the same close scrutiny.

It must be emphasized that improvements in the business environment will not occur until the macroeconomic elements are improved. Hilke and Nelson warn that other practices are relatively less effective in changing the pattern of trade than a focus on macroeconomic influences. A reduction in interest rates and a favorable change in the pattern of trade are not possible until there is a substantial reduction in the federal budget deficit.

2. R&D and Manufacturing

The key success factor regarding research and development (R&D) and manufacturing involves the level of spending in applied R&D, basic R&D, and manufacturing R&D. Historically, American firms have focused on applied R&D while basic R&D was performed at universities. Manufacturing R&D has had relatively little focus in the American semiconductor industry. This historical separation of R&D is not appropriate in semiconductor production. As already noted, the ability to produce memories at a sub-micron level is critical in testing the validity of the manufacturing process. It assures that the process is sound and permits the production of more complex chips, such as microprocessors.

A major action to improve the linkages between research and manufacturing is DoD's support of SEMATECH. The formation of SEMATECH required a change in anti-trust legislation and an increased commitment in cooperation among member firms. Their performance will determine if other manufacturing related research consortiums are attempted in the future.

Unfortunately, the level and risk of additional dollars for research and development hinge around the prevailing cost of capital. Just as the federal budget deficit influences the pattern of trade, the deficit influences the availability and cost of capital. "Problems in obtaining R&D funding at reasonable rates will never be solved until the...federal deficit is reduced substantially." (Dallmeyer, 1987, p.55)

3. People and Culture

The key success factor regarding people and culture is most often manifested in recommendations to improve the educational system in the United States. A stronger emphasis on more technical education is needed as more highly trained and knowledgeable workers are required in "high-tech" firms.

While an improvement in the educational system will be of benefit to all, a change in the focus and thrust of the organization may be just as important to their competitiveness. American companies have been accused of having a short term perspective with an eye on the quarterly financial statements. This focus may have limited their success in capital intensive areas that require longer term investments.

The explanation for American firms' shorter term financial focus is in part the increased risk of capital investments caused by higher interest rates. One can suppose that as short term financial success becomes increasingly more important to the corporation, managers with financial backgrounds will tend to rise more quickly in the organization. The firm, therefore, will focus more on financial performance than on longer term manufacturing capability. The greater risk of capital investments will correspondingly lead to decreased investments in research and development. Over time, the competitive advantage the firm may have enjoyed will be eroded. Once again, the effects of the federal budget deficit can be seen.

Other organizational factors that affect the performance of the firm may result from this shorter term perspective.

> The problem in many Western companies is not that their senior executives are any less capable than those in Japan nor that the Japanese companies possess greater technical

> capabilities. Instead, it is their adherence to a concept of the corporation that unnecessarily limits the ability of individual businesses to fully exploit the deep reservoir of technological capability that many American...companies possess. (Prahalad & Hamal, 1990, p.82)

The failure to exploit this technological capability is the result of failing to identify with the "core competencies" within the organization. Core competencies can be defined as the "...collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple streams of technologies." (Prahalad & Hamal, 1990, p.82) In simpler terms, core competencies are the technologies that are at the "core" of your organization.

Historically, American firms have excelled in developing and introducing advanced technologies. This can be viewed as one of their core competencies. American firms may have lost the focus and guidance of these core competencies. A renewed emphasis on ingenuity and innovation in the semiconductor industry may go a long way in improving competitive performance.

A focus on core competency has many benefits. It helps direct the actions of members of the firm in the same direction. When a firm focuses on its strong points, they are in a position to take advantage of progressing technologies in new and different markets. For example, "Canon's core competencies in optics, imaging, and microprocessor controls have enabled it to enter...markets as seemingly diverse as copiers, laser printers, cameras, and image scanners." (Prahalad & Hamal, 1990, p.83) American semiconductor firms' abandonment of the DRAM marketplace, particularly higher capacity DRAMs that are currently in the introduction phase (recall Figure 1.3), may be considered as an abandonment of one of the core competencies of the semiconductor industry. Once lost, the technology and expertise is difficult to recapture.

Another result of focusing on core competencies is a tendency toward vertical integration. In areas that a firm considers critical, vertical integration is a logical action for protection of those technologies. Prahalad and Hamal emphasize that cultivating core competencies does not mean outspending competitors in research and development or restructuring to become more vertically integrated. However, firms that focus on these critical technologies tend to do just that.

DoD cannot be expected to influence the internal operations of individual firms; however, government policies which reduce the federal budget deficit and help create an environment which is conducive to innovation and technological advance will go a long way toward ensuring that national security objectives are met within the semiconductor industry.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

A. CONCLUSIONS

The health of the semiconductor industry is indeed vital to DoD's ability to incorporate advancing technology into developing weapon systems. However, recent changes in the structure and size of the industry do not necessarily constitute a threat to our national security. Most of the changes that occurred during the 1980s could have been predicted considering the changes in factor prices and the relative maturity of the technologies involved.

The rapid loss in market share that American producers experienced over the past decade is due primarily to the abandonment of the DRAM marketplace. Most American firms were not able to withstand the tremendous drop in memory prices that occurred in the mid 1980s. Japanese producers also lost billions, but were in a financial condition to ride out the downturn. The answer to American semiconductor producers' concerns is not to protect the domestic market until they can produce memories more efficiently. Some evidence already exists that hostilities in the memory market have shifted foreign semiconductor producers' focus to the valuable market for microprocessors. The answer to American producers' concern is a focus on what has historically made them strong: innovation in a free and open marketplace.

The critical elements in the national security question are insuring the security of supply and maintaining DoD's access to advancing technologies. The possibility that semiconductors will be withheld from DoD by foreign suppliers seems unlikely. Even if this unlikely event should occur, it seems reasonable to assume that domestic "captive" producers could meet DoD's needs in an emergency. Foreign producers are more likely to withhold manufacturing technologies from their American counterparts until they achieve a competitive advantage in the process. A more critical concern is maintaining DoD's access to emerging technologies, since it relies on American industry for expertise in identifying and exploiting them in developing weapon systems.

American semiconductor manufacturers should focus on their ability to create new and advancing technologies without reaffirming themselves as leaders in the DRAM marketplace. However, access to advanced semiconductor manufacturing technologies is critical in keeping the U.S. manufacturers strong in the production of advanced microprocessors and other lower volume chips. A reduction in the cost of capital is important in order to maintain the level of research and development required to compete in process technologies.

DoD's and government's efforts should be addressed to lowering the federal budget deficit and encouraging more cooperation among firms. Improvements in anti-trust legislation, along with tax incentives to increase investment and savings, can help stimulate a more competitive business environment, not only for semiconductor firms, but for all related industries as well. An environment must be created that allows domestic firms the flexibility to take a longer term focus on capital budgeting decisions. Again, the positive externalities of a reduction in the federal deficit is the single most important action the U.S. government can take to improve the competitiveness of domestic manufacturers.

B. RECOMMENDATIONS FOR FURTHER STUDY

Due to the limited scope of this thesis, many areas are available for further study. The following list is by no means a complete list of related subject areas, but it should provide some ideas for continued research.

- To what extent is DoD truly reliant on the foreign production and manufacture of semiconductors?
- What U.S. weapon systems are dependent on foreign chips? What possible actions could be taken to safeguard their readiness?
- How effective has SEMATECH been in accomplishing its objectives? Has it been effective in transferring developed technologies to member firms? Have any of its manufacturing technologies been applied to developing weapon systems within DoD?
- What is the relationship between SEMATECH's smaller firms and its larger members?
- Will lower interest rates and the corresponding lower cost of capital be enough to increase the level of investment

in research and development within the semiconductor industry? Are other factor prices influencing the balance of trade?

- How important is the DRAM industry to the long term competitiveness of American semiconductor producers? Is the DRAM market out of the reach of domestic producers? Will a reduction in the cost of capital improve the industry's opportunities to reenter the DRAM marketplace?

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